Supernova Hydrodynamics: The effects of a radiative shock on hydrodynamic instabilities

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NIF User Group Meeting

Outline

- Motivation and background
  - Core-collapse, red supergiant supernovae
  - Previous Omega experiments

- Modeling of supernova-relevant radiation hydrodynamics experiments
  - ARES simulations
  - 1D HYDRA simulations
  - Preliminary CRASH simulations

- Experiments
  - Initial experimental tests
  - Upcoming physics experiments

NIF Rad-SNRT Team – past and present

Principal Investigator: Carolyn Kuranz

Liaison scientist: Hye-Sook Park (LLNL)

University of Michigan Participants

Paul Drake (Professor)

Carolyn Kuranz (Research Scientist, PI)

Chan Huntington (Grad Student)

Forrest Doss (Former Grad Student, LANL)

Christine Krauland (Grad Student)

Eric Harding (Former Grad Student, SNL)

Michael Grosskopf (Research Engineer)

Donna Marion (Research Engineer)

Sallee Klein (Research Engineer)

Eric Myra (Research Scientist)
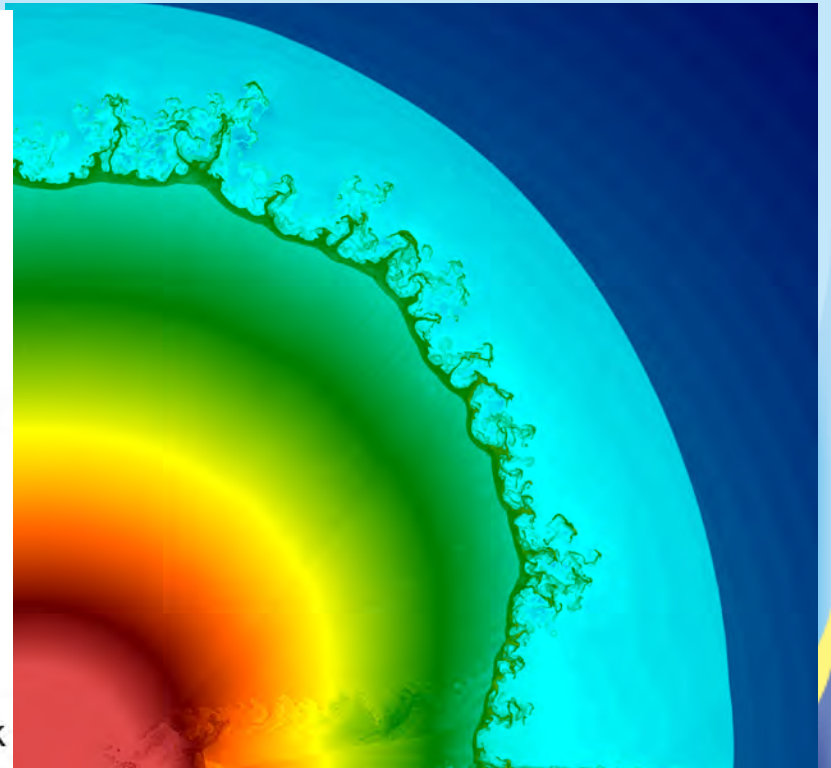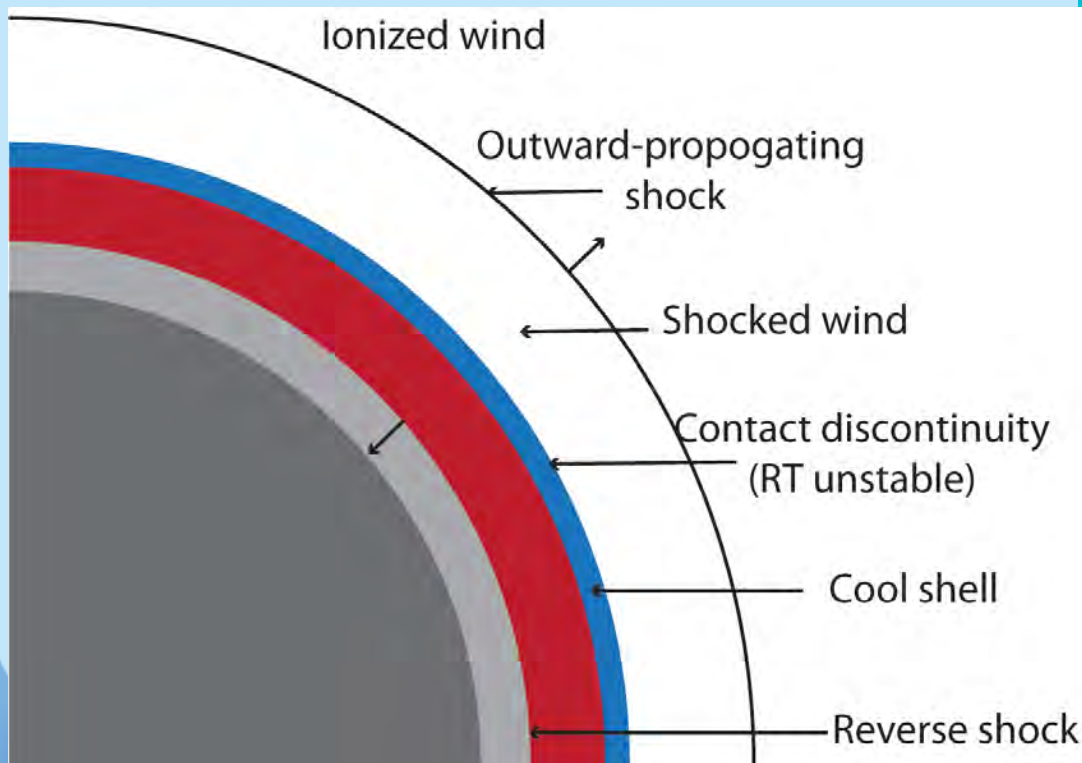
Bruce Fryxell (Research Scientist)

Additional Participants

Bérénice Loupias (CEA)

Tomasz Plewa (Florida State),

David Arnett (Univ. of Arizona)

Craig Wheeler (Univ. of Texas)

Jon Larsen (Cascade Sciences)

LLNL/GA/LANL Participants

Hye-Sook Park (experiment, RI)

Brian MacGowan (AI)

David Bradley (experiment)

Emilio Giraldez (GA, target)

Alex Hamza (target)

Freddy Hansen (experiment)

Dan Kalantar (experiment)

Chris Keane (science)

Joe Kilkenny (science)

Andrew MacPhee (experiment)

Brian Maddox (experiment)

Aaron Miles (design)

Kumar Raman (design)

Abbas Nikroo (GA, target)

Bruce Remington (science)

Harry Robey (design)

Larry Suter (science)

Russell Wallace (TFE)

Abbas Nikroo (GA, target)

Emilio Giraldez (GA, target)

John Kline (LANL, science)

George Kyrala (LANL, science)

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The study of radiative effects on the Rayleigh-Taylor instability is relevant to core-collapse, red supergiant

Ionized wind

Outward-propogating shock

Shocked wind

Contact discontinuity (RT unstable)

Cool shell

Reverse shock

Nymark et al., Astron. & Astro. 449, 171 (2006) ☐X-ray emission from radiative shocks in type II supernovae☐

Plewa hydrodynamic simulation of red supergiant showing RT instability develop in shocked wind region

Shock waves become radiative when...

Radiative energy flux would exceed incoming material energy flux

Where post-shock temperature is proportional to u_s^2

The ratio of these energy fluxes is proportional to u_s^5/ρ_o

Implying threshold velocities ....

$$\sigma T_s^4 \qquad\qquad \rho_o u_s^3/2$$

downstream $\longrightarrow$ $\longleftarrow$ **Upstream preheated**

Material	Xe (Omega)	Foam (NIF)
Density	0.01 g/cc	0.02 g/cc
Threshold velocity	60 km/s	150 km/s
Drive Pressure	40 Mbar	200 Mbar

NIF can drive radiative shocks in materials that are dense enough to produce observable hydrodynamic instabilities
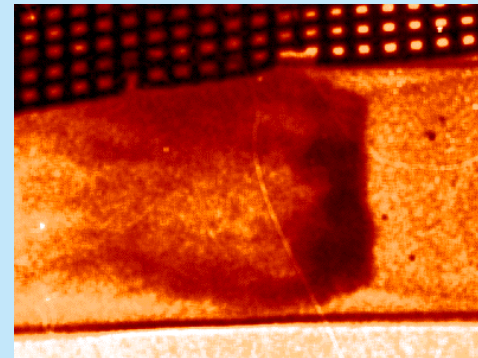
NIF experiment combines RT experiment and radiative shock experiment
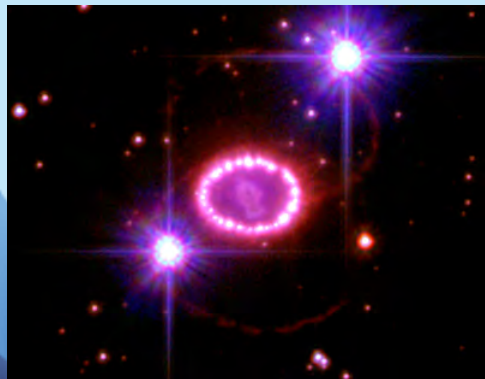
Supernova relevant hydrodynamics

Supernova relevant radiative shocks
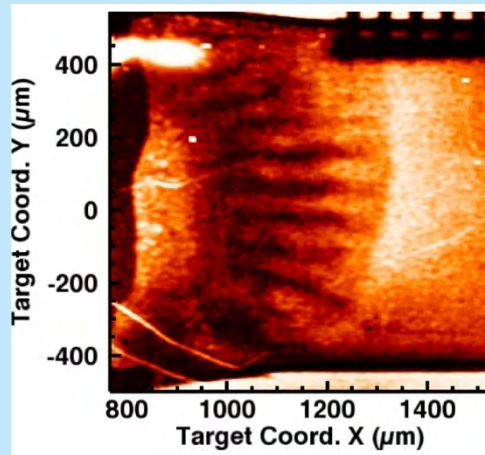
Scaled model of instabilities at H/He interface of SN1987A
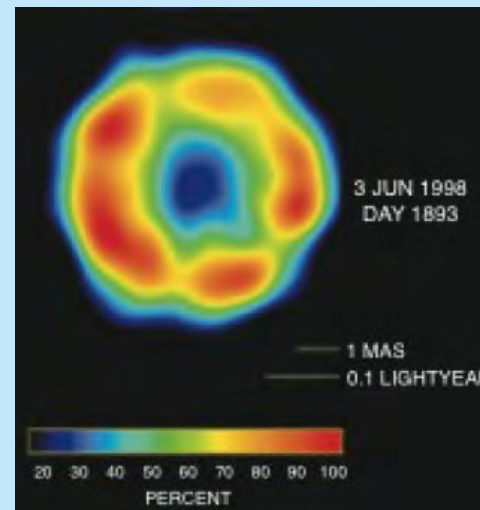

20x shock compression by radiative losses

SN1987A, a core-collapse, blue supergiant supernova (HST)

SN1993J, structure may be due to radiative collapse (Bartel, Science, 2000)
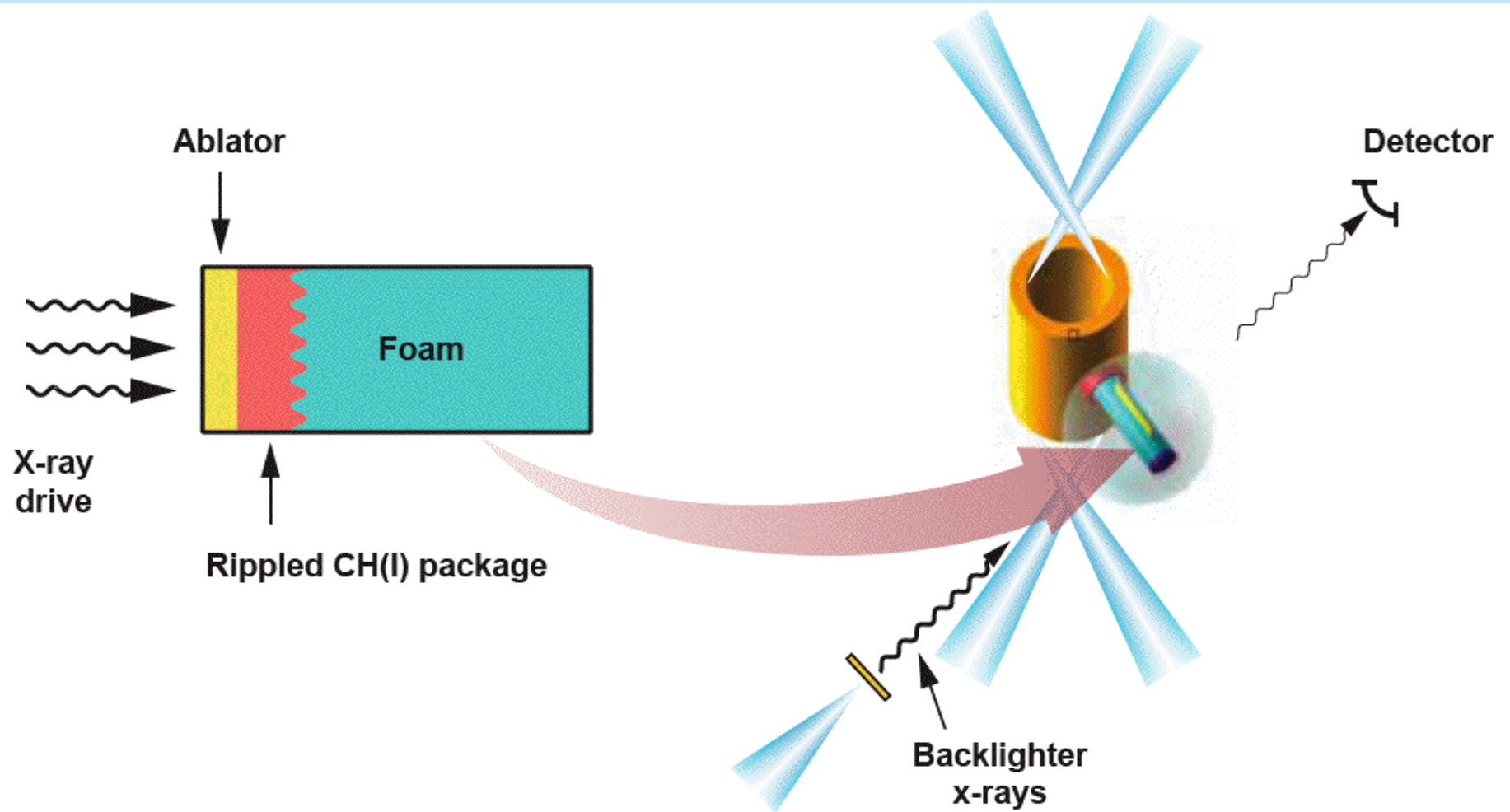
Unlike Omega, NIF can study the effects of a radiative shock on hydrodynamic instabilities; a regime that has not been previously accessed

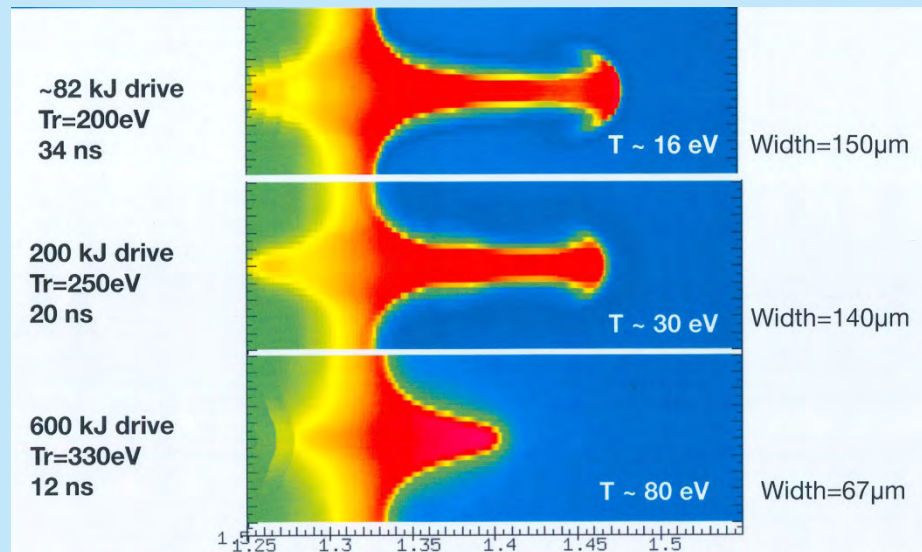# Only NIF can probe this novel high-energy-density system
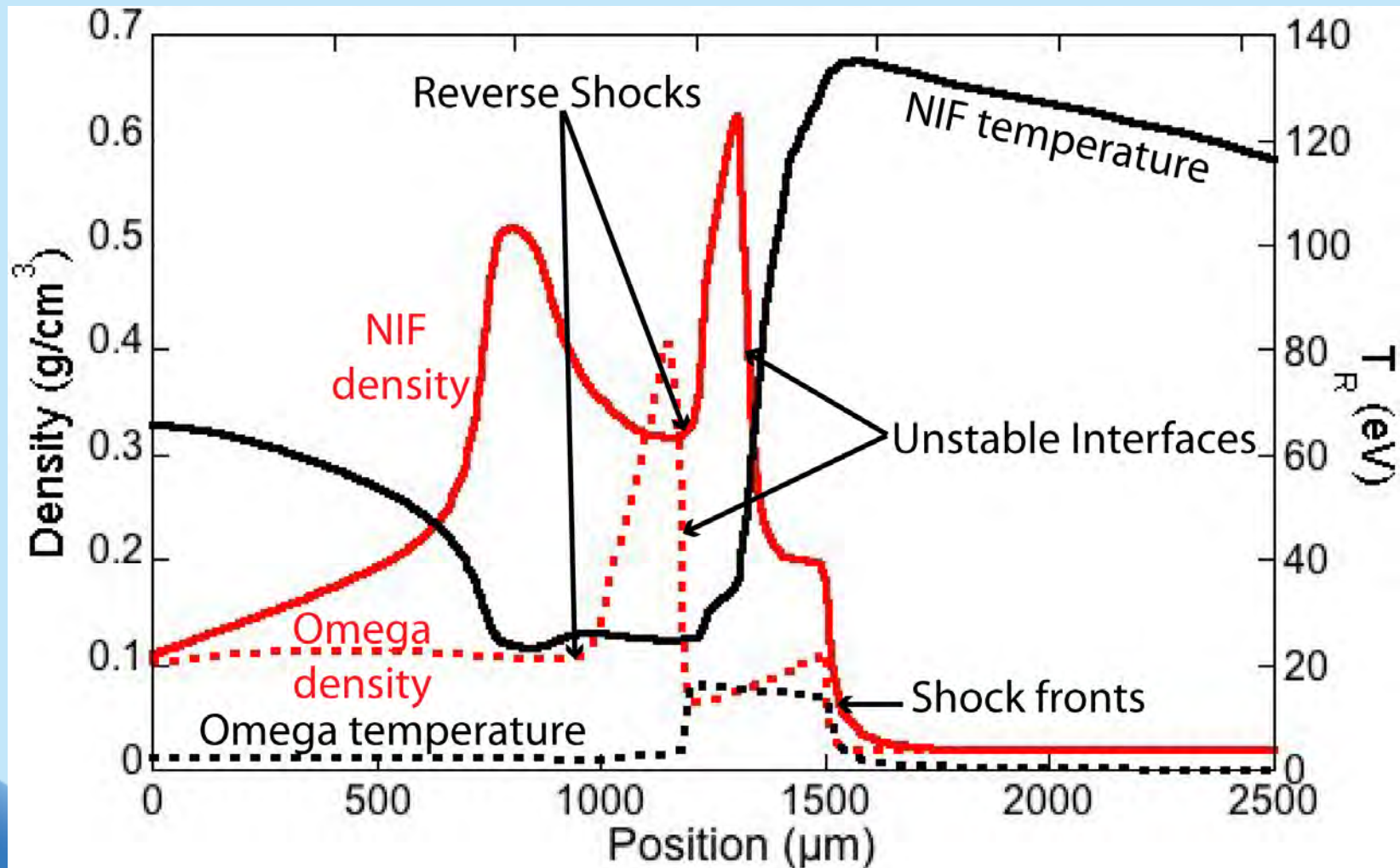
1D Hyades simulation results of NIF experiment where an unstable interface is heated by a ~140 eV shock

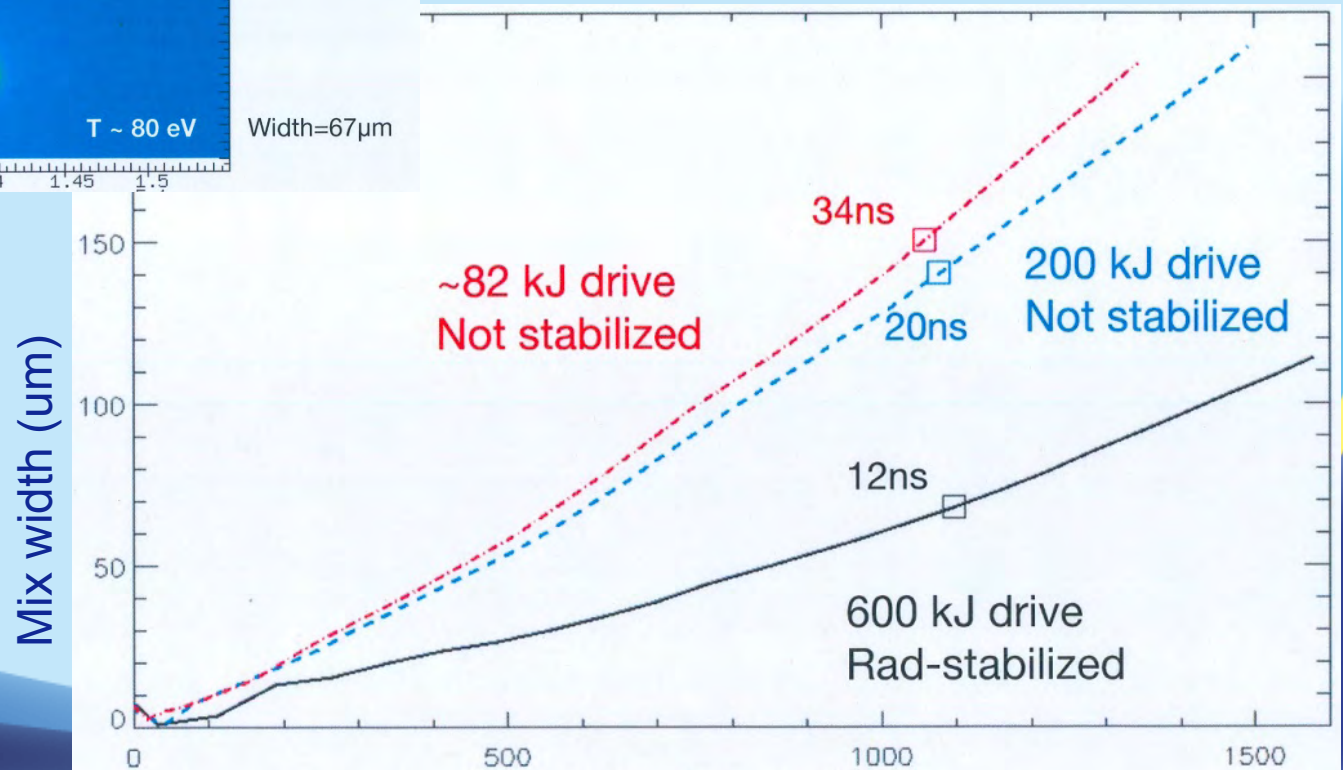# The NIF experimental design uses a Michigan-assembled target package

Ablator

Foam

X-ray drive

Rippled CH(I) package

Detector

Backlighter x-rays

ARES simulation results show reduced RT growth

~82 kJ drive
Tr=200eV
34 ns
T ~ 16 eV   Width=150μm

200 kJ drive
Tr=250eV
20 ns
T ~ 30 eV   Width=140μm

600 kJ drive
Tr=330eV
12 ns
T ~ 80 eV   Width=67μm

Simulations by
Miles and Raman

Interface displacement (um)

Kuranz, Astro. and
Space Sci., 2011

34ns

~82 kJ drive
Not stabilized

20ns

200 kJ drive
Not stabilized

12ns

600 kJ drive
Rad-stabilized

Mix width (um)

We infer reduced growth using ablative stabilization theory and 1D Hydra simulations

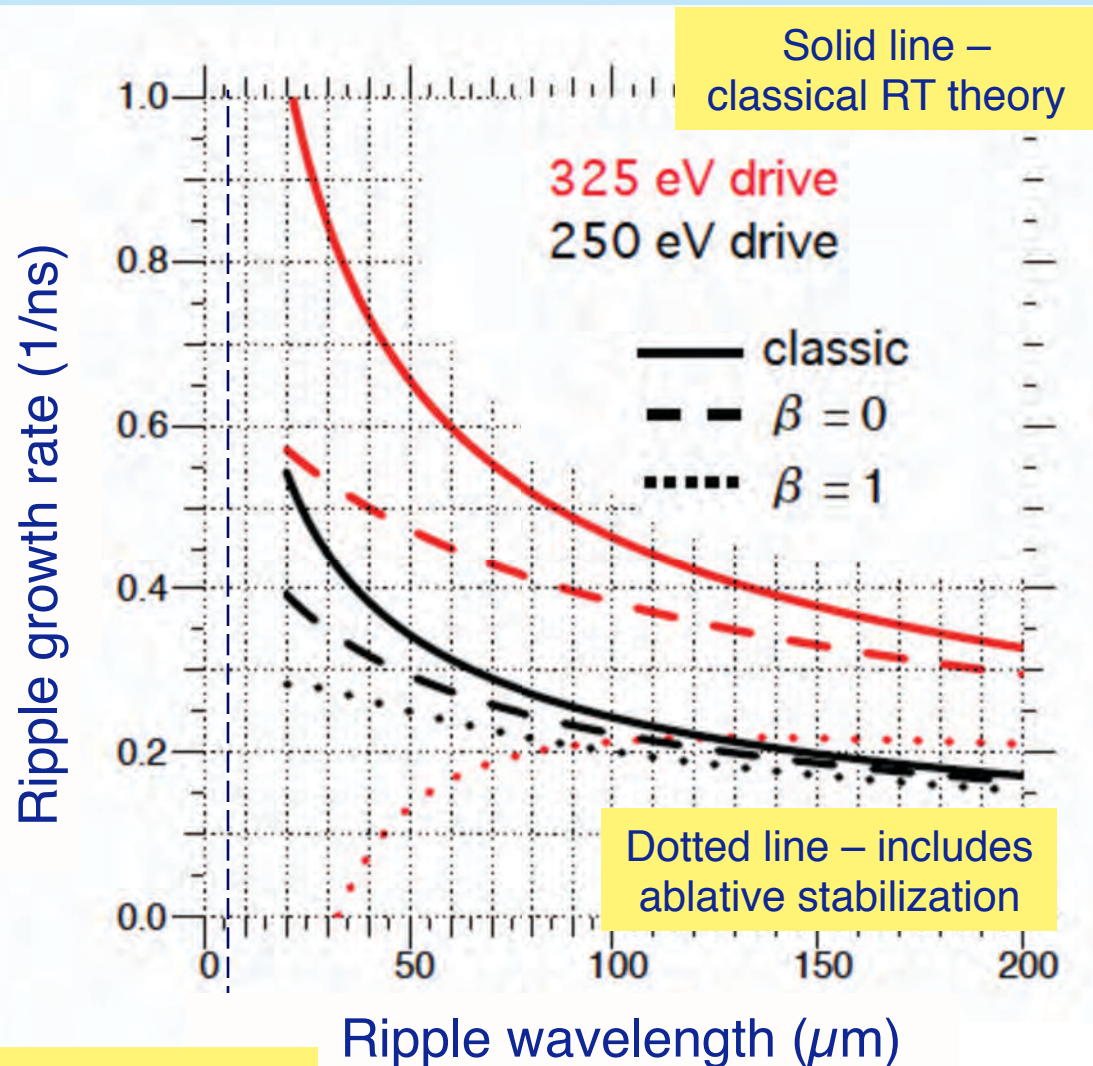$$\gamma = \alpha \sqrt{\frac{kg}{1 + kL_m}} - \beta k v_a$$

k - wave number
g - acceleration
α and β are constants
L_m - density gradient scale length
v_a - ablation velocity

Solid line – classical RT theory

325 eV drive
250 eV drive

—— classic
– – $\beta = 0$
····· $\beta = 1$

Ripple growth rate (1/ns)

Ripple wavelength (μm)

Dotted line – includes ablative stabilization

We have performed preliminary simulations with the CRASH code

CRASH simulations performed with
- multigroup radiation
- 3 levels of AMR
- Tabular opacity and EOS
- 128 zones per wavelength

High drive

Low drive
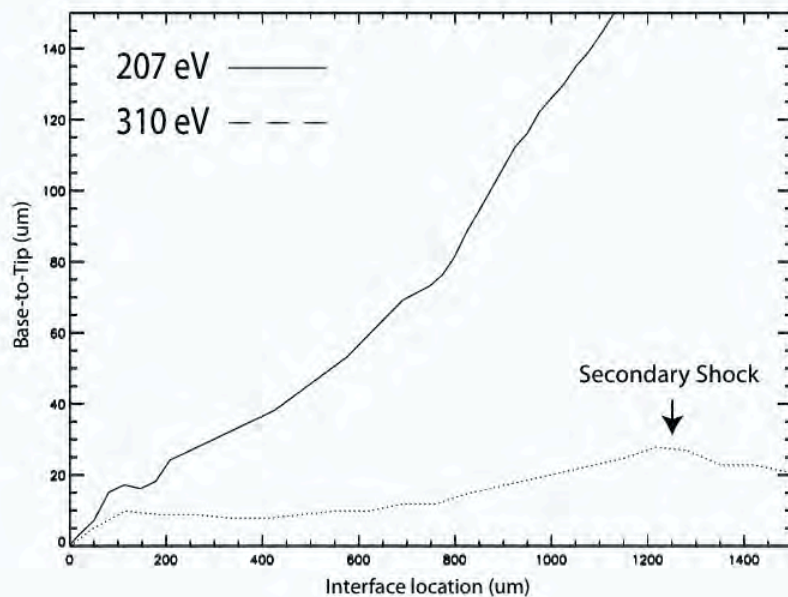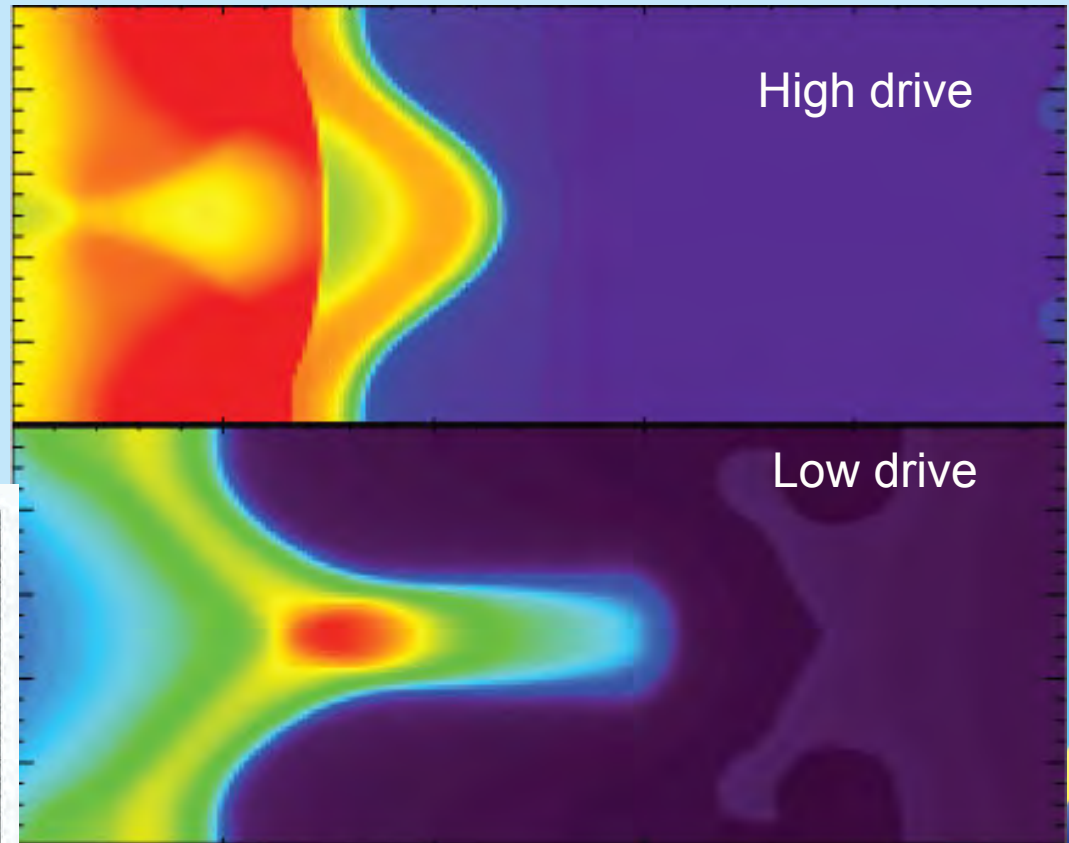
See Matt Trantham and Mike Grosskopf's posters and Ken Powell's talk tomorrow
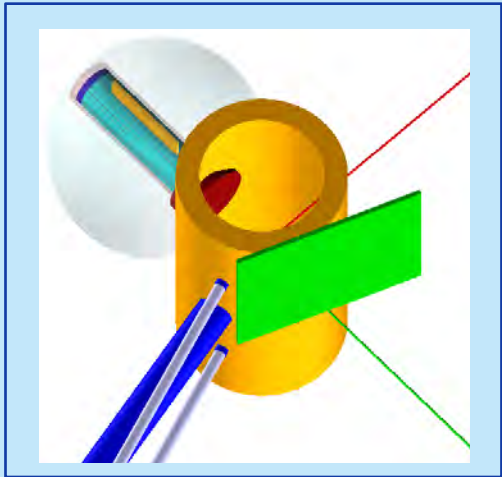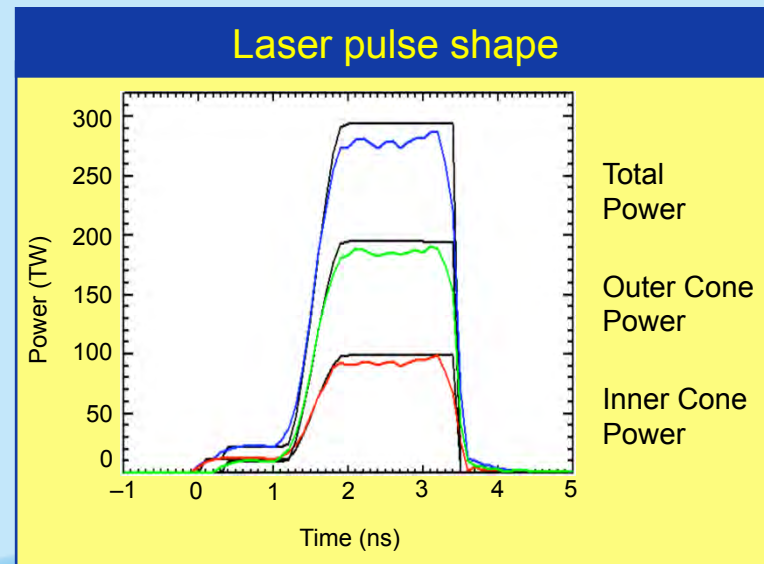
Hohlraum test experiments yielded T_R of 330 eV

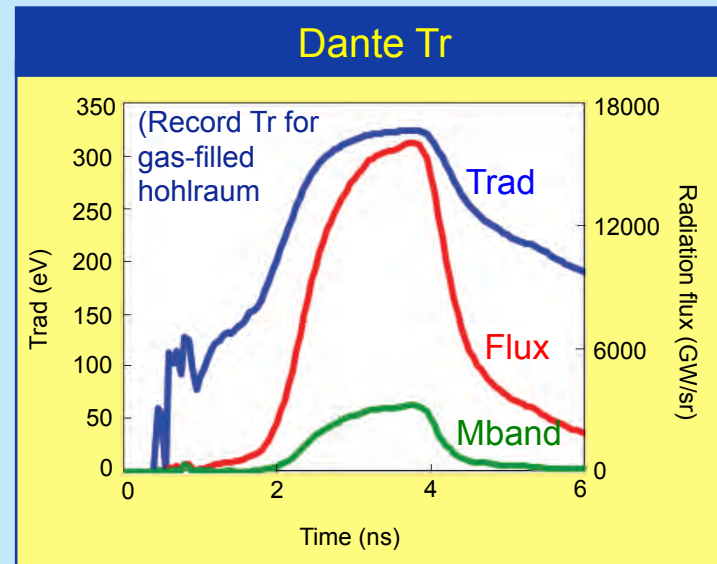**UU_RSRT_HOHL-B**
0.7 scale Au hohlraum
**293 torr Neopentane fill**

Kuranz, Astro. and Space Sci., 2011

Highlights of 2009 experiment: We developed a $T_r{\sim}325$ eV hohlraum to drive Rayleigh-Taylor instabilities behind a radiative shock

Dante Tr

(Record Tr for gas-filled hohlraum)

Trad

Flux

Mband

Laser pulse shape

Total Power

Outer Cone Power

Inner Cone Power

NIF shot-091124 used 589 kJ with 189 beams on NIF

(Kuranz, HEDLA, 2010)

We demonstrated a technique to assess background signals that has since been used extensively for ICF shots

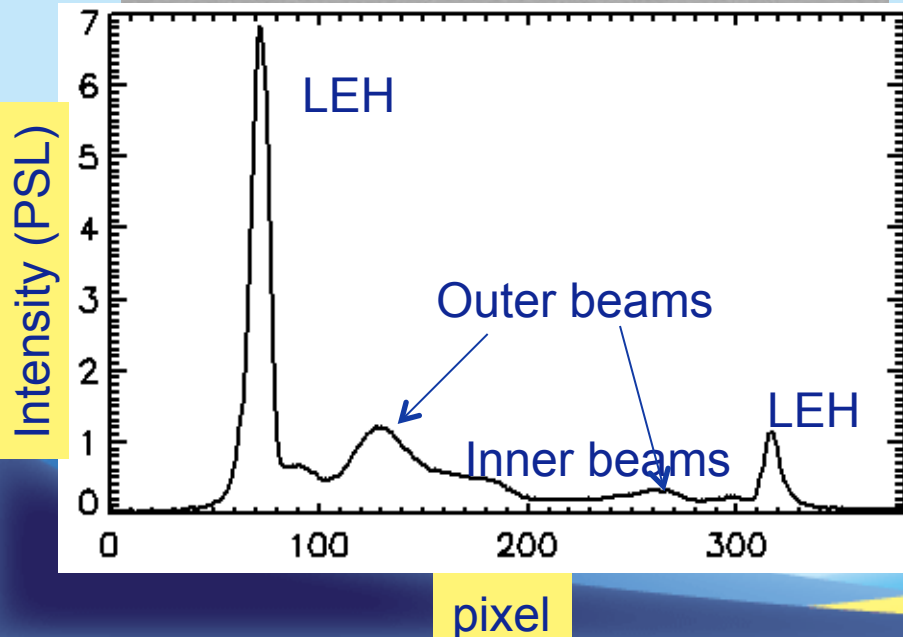

N091124
Scl0.7, gas, DIM90-315, 1198 mm
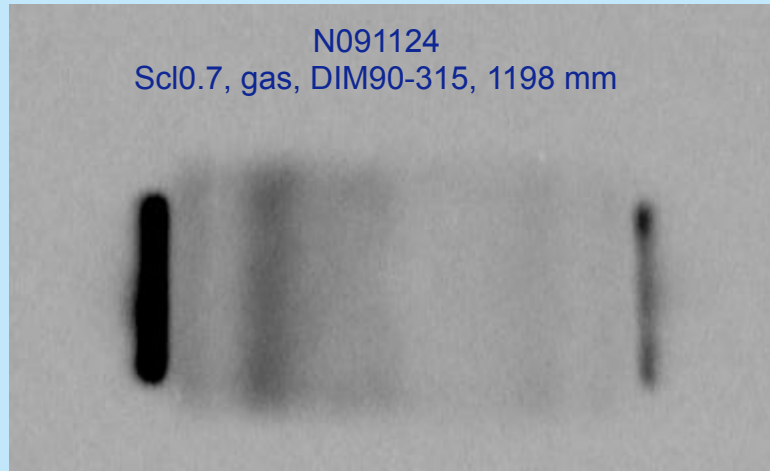
Estimated background energies
Outer beams: 50 keV

Inner beams: 60 keV

LEH glow: 45 keV

Background must be reduced by 3 orders of magnitude, which requires 1 mm Au shielding on hohlraum
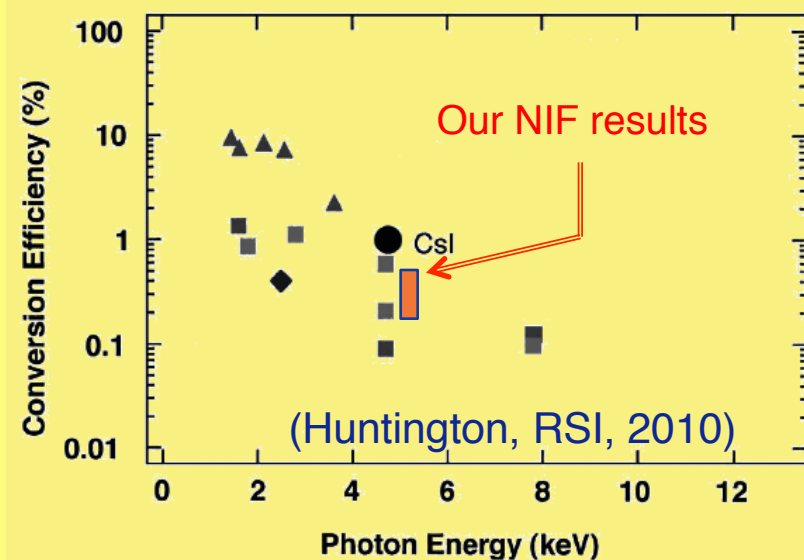
Analysis performed by Hye-Sook Park

2009 Backlighter test experiments measured the required point projection vanadium backlighter brightness

Vanadium backlighter on a tilted pinhole package

TARPOS

1.0 mm

8 beams, 467 J, 88 ps

V foil
0.3 x 0.3 mm
5 μm thick

DIM90-45
(x-ray detector)
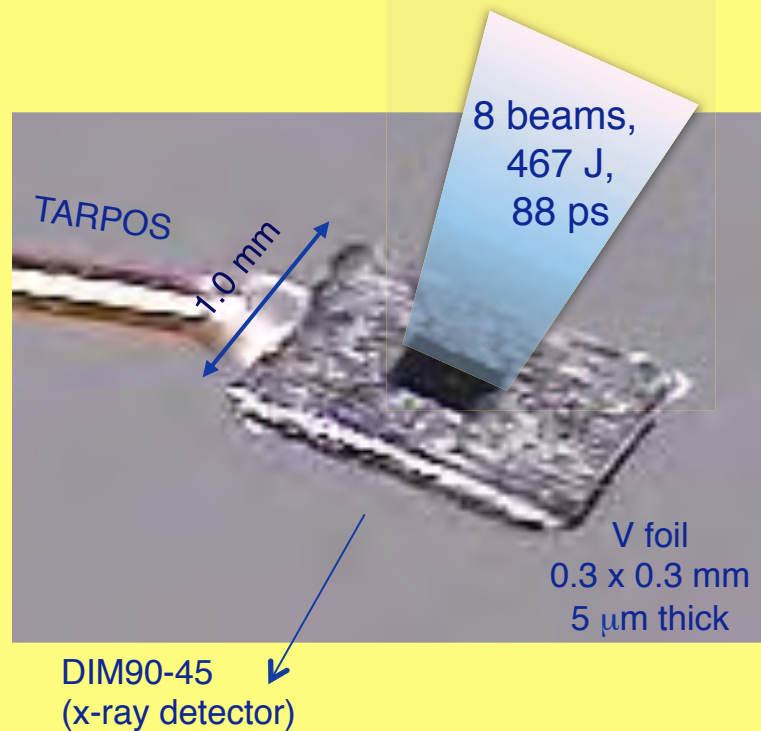
Absolute vanadium yields are measured by Ross pair filters

Our NIF results

CsI

(Huntington, RSI, 2010)

- This is sufficiently bright to observe the ripple growth
- The predicted SNR is ~10

Shot plan: Integrated tests in FY12 and physics experiments in FY13

Shot	T_R	Delay times	wavelength	Notes
			FY12	
1	330 eV	12 ns	100 μm	Integrated test shots
2	330 eV	> 12 ns	100 μm	Locate stagnation shock
			FY13	
3	330 eV	t_2	100 μm	
4	200 eV	34ns	100 μm	
5	330 eV	t_3	100 μm	Repeat or t_3 for acceleration measure
6	200 eV	T_2	100 μm	
7	200 eV	T_3	100 μm	Repeat or T_3 for acceleration measure

Summary

- We are performing a novel experiment to study effect of radiation on hydrodynamic instabilities
- This experiment is relevant to astrophysics and HED physics
- Continue experimental modeling effort
- We performed 2 shots in FY10
- We plan integrated physics shots in this FY12/13
  - 2 different drive temperatures
  - 2 different delay times
  - 1 repeatability or acceleration measure